TEMPEST
A Computer Program for Estimating
Temperature on the
Northeast Continental Shelf

by

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ABSTRACT

A method is presented for estimating the mean surface or bottom temperature at any location on the northeast continental shelf on any day of the year. The method is based on observations made by the Northeast Fisheries Center MARMAP program between 1977 and 1987. A disk with computer programs for making temperature estimates is included at the end of the report.

Introduction

This report describes a computer program for estimating the expected or mean surface and bottom temperatures at any location on the northeast continental shelf for any day of the year. The program and necessary data files are provided on a disk included with the report.

Program Name:	TEMPEST
Computer:	IBM PC or compatible
Executable file:	TEMPEST.EXE or TEMPEST7.EXE
Language:	Turbo Pascal 4.0 with Graphix Toolbox
Current version:	2.1 January 1989
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The following sections present an overview of the program, the data set upon which the temperature estimates are based, the procedures used to make the estimates and operating instructions for the program. The program code is included on the disk in the file TEMPEST.PAS and may be viewed by listing the file on your computer. The data files CYCLETOP.DAT and CYCLEBOT.DAT may also be viewed by listing them.

The program provides an easy method for obtaining the characteristic temperature patterns anywhere on the northeastern continental shelf. This information may be useful for planning experiments by identifying the range of temperatures likely to be encountered in an area, for the quality control of temperature observations from field work, or for biological modeling efforts by providing a spatially and temporally realistic temperature field. The temperature field generated by the program may also serve as a consistent reference against which other observations, scattered in space and in time, may be compared.

Description

Estimates of surface or bottom temperature at any location on the northeast continental shelf are made using curves describing the annual temperature cycle at standard MARMAP station locations (see Figure 1 and the DATA section below). These curves represent the best fitting sum of three harmonics (frequencies of one, two and three
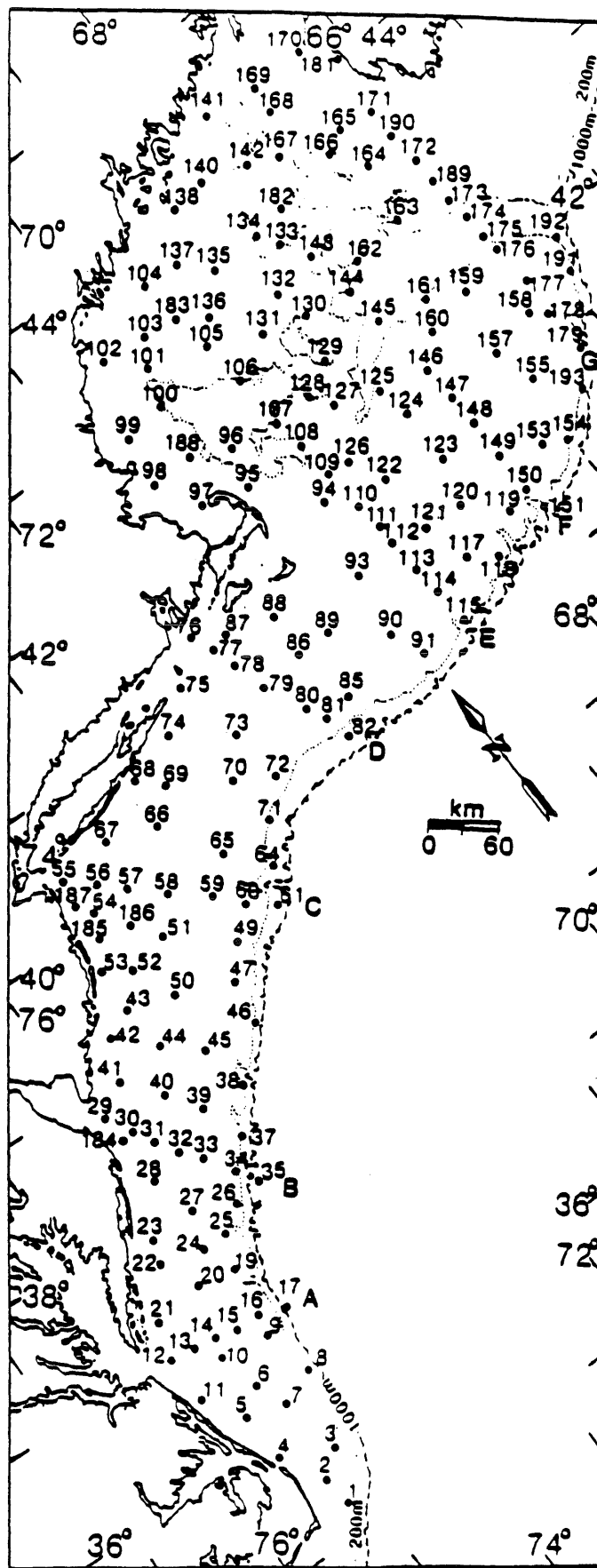
Figure 1. Locations of the MARMAP standard stations.

cycles per year) to all surface or bottom observations at the MARMAP station. The temperature at an arbitrary location on the shelf is estimated by weighting the temperatures at nearby MARMAP stations inversely to the square of the distance from the station to the desired location. An estimate of the uncertainty of the temperature estimate is also made.

A temperature estimate can be made for a particular day of the year or for an entire annual cycle. In the latter case, the annual cycle is plotted on the computer screen and, if desired, written to a disk file in the form of daily temperature values.

The program requires six files to run - a program file, two font files, two data files and a message file. The program is written in Turbo Pascal (version 4.0) with graphics routines included from the Turbo Pascal Graphix Toolbox. There are two versions of the compiled executable program file:

TEMPEST.EXE - for any MS-DOS computer
TEMPEST7.EXE - for use with a coprocessor (8087 or 80287)

The font files are 4X4.FON and 8X8.FON. The two data files are CYCLETOP.DAT and CYCLEBOT.DAT and contain the coefficients for the surface and bottom annual cycles. The message file is ERROR.MSG.

The Data

The data upon which the temperature estimates are based were obtained by the Marine Resources Monitoring, Assessment and Prediction (MARMAP) program. MARMAP is an interdisciplinary program to measure the distribution of plankton, nutrients and water properties over the continental shelf from Cape Hatteras to the Gulf of Maine. Observations have been made on

three to six survey cruises per year at over 180 standard station locations (see Figure 1). The stations are separated by about 30 km, although not all stations were occupied on each cruise. From 1977 through 1987 the program made hydrographic measurements on 49 cruises.

On nearly all of the cruises water properties were measured using water bottles and reversing thermometers at up to 15 standard depths. In 1987 some of the data was obtained using a conductivity/temperature/depth (CTD) profiling instrument. The accuracy of the temperature measurements is approximately -0.02 C. The method described in this report uses only the surface and near bottom temperature observations from the MARMAP data set. An observation had to be within 5m of the surface to be considered a surface value and within 10m of the bottom to be used as a bottom observation.

Determining the Annual Temperature Cycle at a MARMAP Station

To determine the annual cycle of surface or bottom temperature for a standard MARMAP station, all of the observations at the station were combined, regardless of year, with the dates expressed only as Julian Day. If there were at least 10 observations for the station and at least one in each quarter of the year, an annual curve was calculated.

The annual curve fit to the data is the sum of three sinusoidal components - having frequencies of one, two and three cycles per year. To fit the different harmonic components, a multiple regression model was used with the form:

$$T = \sum_{j=1,3} [M_j + A_j \cos(2\pi * JD / P_j) + B_j \sin(2\pi * JD / P_j)]$$

where:

T	=	temperature
M_j	=	the mean temperature for the jth component
JD	=	Julian day
A_j	=	cosine amplitude for the jth component
B_j	=	sine amplitude for the jth component
P_j	=	the harmonic period for the jth component

The independent variables are the cosine and sine terms, evaluated for the Julian day of each observation and the harmonic period being considered. The model then has the form:

$$T = M + A*X1 + B*X2$$

where X1 is the cosine variable and X2 is the sine variable. The values of A and B were determined following the method described in the Statistical Package for the Social Sciences (SPSS Inc. 1975, p 323-329):

$$A = \frac{SP[T1]*SS[2] - SP[T2]*SP[12]}{SS[1]*SS[2] - SP[12]*SP[12]}$$

$$B = \frac{SP[T2]*SS[1] - SP[T1]*SP[12]}{SS[1]*SS[2] - SP[12]*SP[12]}$$

$$M = T - A*\overline{X1} - B*\overline{X2}$$

where T represents the observed temperature values and SS and SP stand for the sum of squares and the sum of products:

$$SS[1] = \Sigma \ (X_{1i} - \overline{X}_1)^2 = \Sigma X_{1i}^2 - (\Sigma X_{1i})(\Sigma X_{1i})/N$$

$$SP[12] = \Sigma(X_{1i} - \overline{X}_1)(X_{2i} - \overline{X}_2) = \Sigma(X_{1i} \ X_{2i}) - (\Sigma X_{1i})(\Sigma X_{2i})/N$$

where N is the number of points and the summations are from i = 1 to N.

The curve fitting procedure first fits an annual harmonic (P = 365 days) to the original data set. The mean, cosine and sine coefficients are determined by the above expressions. The significance of the regression coefficients are tested as described by Fofonoff and Bryden (1975) and by Brownlee (1965). If the annual curve is significant at the 95% level, it is accepted and the residuals (the differences between the original data and the calculated annual curve) are the input data for fitting the second harmonic with period 365/2 days. The significance of this curve fit is tested. If accepted, the residuals are again determined and a third harmonic with P=365/3 is fit to them. Since the original data are not uniformly spaced in time, the residuals from each harmonic will not necessarily have a zero mean. The second and third harmonics will have small mean values associated with them. The mean value for the year is the sum of the three means.

The standard deviation of the original data from the combined annual curve is determined. Any points that are more than two standard deviations from the calculated curve are identified. The curve fitting process is repeated with these points omitted. The results of the second curve fitting are the values accepted and used.

For each MARMAP station a record was written to a coefficient file containing:
1. the station number
2. the standard position for the station
3. the standard bottom depth for the station
4. the nine annual curve coefficients (mean, cosine and sine amplitude for each of the three harmonics)
5. the standard deviation of the original data from the annual curve.

The file CYCLETOP.DAT contains data for the 180 stations for which surface temperature curves could be calculated. The file CYCLEBOT.DAT contains data for the 167 bottom temperature curves which could be calculated.

An example of the curve fitting results is shown in Figure 2 for the bottom temperature at MARMAP station 56. The solid line in the figure is the mean annual curve and the dashed lines represent plus and minus one standard deviation from the mean. The original data points are plotted and keyed by year. The calculated mean curve is able to follow the observations quite closely. The standard deviation results more from real interannual variability in the data than from an inability of the curve fitting method to represent the original data.

Estimating Temperature At a Location

To estimate the temperature at a given location on the shelf, the nearest MARMAP stations that have annual temperature curves are first identified. The list of MARMAP stations is searched to locate stations that are within a given range of latitude and longitude, as described below. If only one or no stations are found, the search distances or ranges are doubled. If no stations are again found, the distances are tripled and finally quadrupled. If no stations are found within four times the original search distances, no temperature estimate is attempted.

The original search distances depend upon location. South of 39°N (near Delaware Bay) the isobaths are essentially north-south, and the program will search further in the along-shelf direction than in the cross-shelf direction. The original search distances are 0.2 latitude (22 km) and 0.15 longitude (12 km). On the shelf east of Long Island to Georges Bank the isobaths are east-west and the original search distances are 0.1 latitude (11 km) and 0.25 longitude (21 km). In the New York Bight (between the two previous areas) and in the Gulf of Maine the original search area is about square, 0.15 latitude (16 km) and 0.20 longitude (16 km).

When the nearby stations have been identified, a weighting factor is assigned to each station. The factor is inversely proportional to the square of the distance from it to the given location. The sum of the weighting factors is 1. The weight assigned to a station represents the proportion it contributes to the final temperature estimate. The coefficients for the annual curve at the desired location are calculated by a weighted average of the coefficients from the contributing MARMAP stations.

The annual curve for each standard MARMAP station has an associated standard deviation. This is the standard deviation of the original observations from the calculated annual curve. When combining the contributions from the different stations to estimate the temperature at an arbitrary point, an estimate of the uncertainty is also made by weighting the variance (square of the standard deviation) for the different stations. The uncertainty estimate has two parts - one related to estimating the mean value at the point and the other to estimating the uncertainty about the mean. With N standard stations contributing, each having a variance v and an assigned weight a, the total variance estimate is:

$$V = \sum_N a_i^2 v_i + \sum_N a_i v_i$$

where the first summation represents the uncertainty of the mean and the second represents the weighted average uncertainty about the mean. The uncertainty listed for a temperature estimate is the square root of this variance.

Cautions in Interpreting the Temperature Estimates

1.   Near the seaward edge of the continental shelf actual temperatures could be significantly different than estimated by this
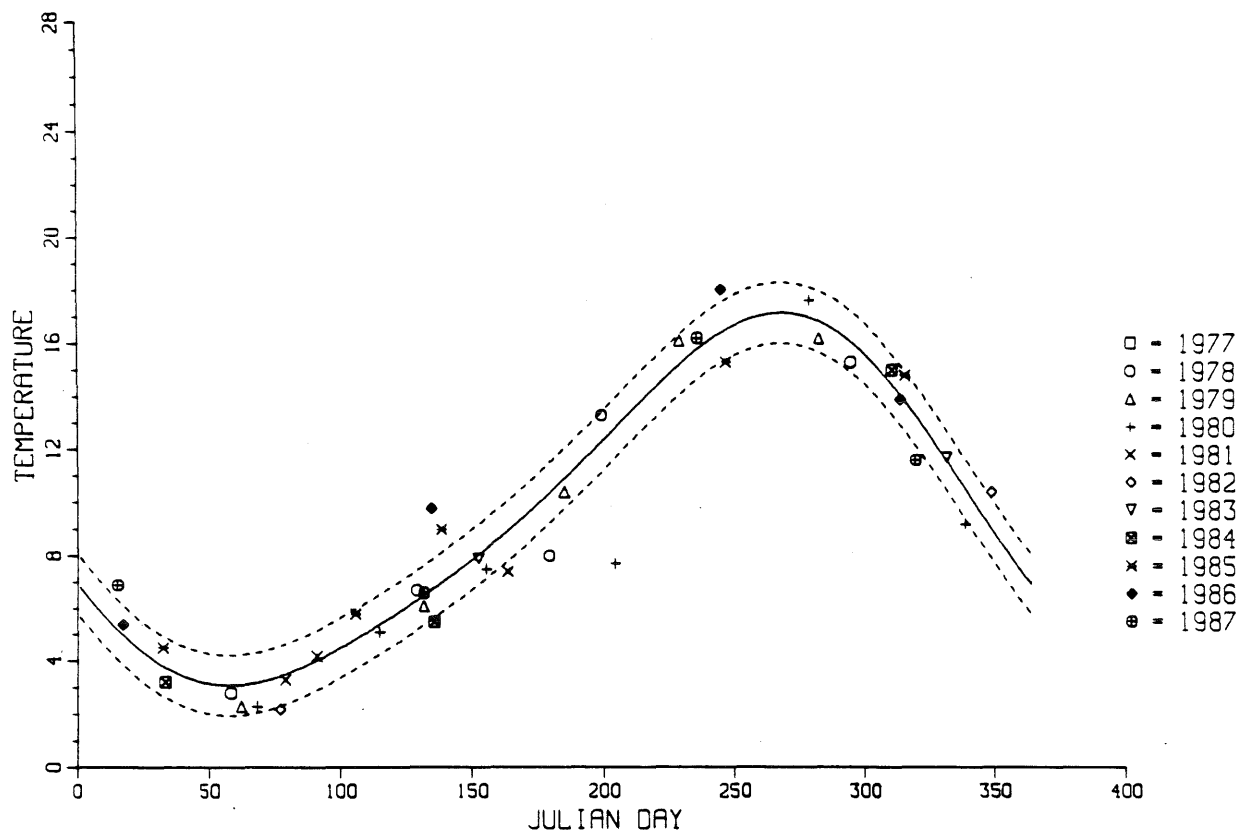
Figure 2. Calculated annual curve (solid line) for the bottom temperature at MARMAP station 56. The dashed lines represent plus and minus one standard deviation from the mean curve. The original data points are plotted with symbols indicating the year of observation.

program, particularly on the bottom, due to movement of the shelf/slope front.

2.   The peak surface temperature generally occurs in July or August. This period was not well sampled at all MARMAP stations and the temperature peak may not be well defined in all of the calculated annual curves.

3.   When estimating bottom temperature, the depth range of stations contributing to the estimate should be considered. When the program provides the opportunity, the user should drop from the calculations stations having a significantly different depth than at the location of interest.

4.   Estuarine and nearshore regions are not sampled in the MARMAP surveys (see Figure 1). Local effects are likely important in determining temperature in these areas. Therefore the method presented here would not be reliable in those regions.

Operating Instructions for TEMPEST

User entries are indicated in bold type.

1.   With the computer on, set the default drive to the drive containing the program, font and data files. At the > prompt type the name of the appropriate program (for example: **TEMPEST7**).

2.   The program begins execution and asks the user to choose either surface or bottom temperature estimates. The proper response is to enter either **S** or **B**. The program then reads the file containing the coefficients for the surface or bottom annual temperature curves, which takes a few seconds to complete.

3.   The program then presents two options: 1) to estimate temperature at a given location on a given date, 2) to estimate the annual temperature cycle at a given location. This option requires a computer with a graphics adapter: CGA, EGA, VGA or Hercules monochrome. The user should choose an option by entering either **1** or **2**.

Option 1 - Temperature For a Given Date

4.   The program asks for the desired latitude, longitude and date. The latitude and longitude are in integer degrees and decimal minutes with a space between (for example: **40 45.7**). The date is entered as integer month and day with a space between (for example: **7 25** for July 25).

5.   The program searches for the MARMAP stations closest to the given position. The stations are listed with station number (see Figure 1), temperature (estimated from the annual curve for the station), weighting factor, distance to the given position and bottom depth. The program then asks if the user wants to drop any of the identified stations from the estimating procedure. The user enters **Y** for yes and **N** for no. If yes, the user is asked to enter the station number to be dropped. The program then inquires if another station is to be dropped. The user may enter **Y** and continue dropping stations from the list.

6.   The program then prints:

a.   the given latitude, longitude and date
b.   the estimated temperature and its uncertainty
c.   the calculated temperature, weighting factor, distance and depth for each con tributing MARMAP station.

7.   The program asks if the user wants to run the program again. If **Y**, the program returns to step 3. If **N**, the program stops.

Option 2 - Annual Cycle of Temperature at a Location
[This option requires a graphics adapter on your computer]

8.   Steps 4 and 5 above are followed, with no date being requested in step 4.

9.   The information for the MARMAP stations being used is listed. The temperatures listed are for July 1, to provide an indication of the inter-station variability. When ready the user presses **Enter**. The estimated temperature for each day of the year is calculated and the annual cycle is plotted on the computer screen. The maximum and minimum temperatures and the dates on which they occur are listed under the plotted annual cycle.

10.   When done viewing the plot, the user presses **Enter** and is provided with five options:

1. exit the program
2. enter a new position
   (return to step 3).
3. list the estimated temperatures for 45 day period.
4. review the annual cycle plot
   (for example: return to step 9).
5. write the temperatures for the year to a disk file.

11.   If a list of temperatures (option 3) is selected, the program asks for a starting date, which is entered as integer month and day (for example: 4 10 for April 10th). The program offers to write the temperatures to a disk file. A file is created with the name TSXXYY.LST or TBXXYY.LST where the S or B indicate surface or bottom values, XX is the degrees of latitude and YY the degrees of longitude.

Since direct output to a printer from Turbo Pascal is compatible with only Epson printers, this disk file provides a way for any user to get a hard copy output of the list by a DOS Print command. The program then lists the date and temperature for 45 days begin-ning with the given date. The option list in step 10 is then repeated.

12.   If a disk file of the daily values is chosen (option 5) a text file is created with the name TSXXYY.DAT or TBXXYY.DAT. The S or B indicates surface or bottom values, XX is the degrees in latiutude and YY the degrees of longitude. The date and estimated temperature are then written to the file for each day of the year. The option list in step 10 is then repeated.

References

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